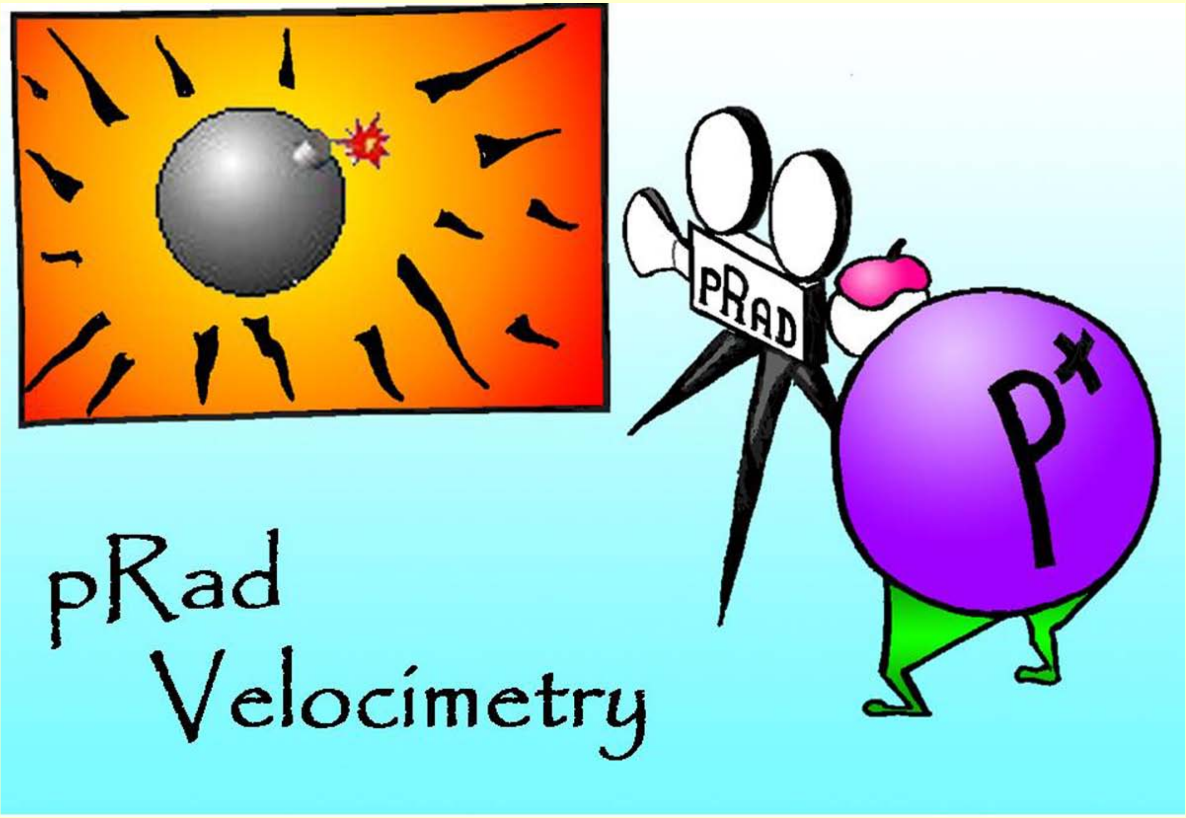
The LANL Proton Radiography facility and velocimetry capabilities

Proton Radiography (pRad), invented at Los Alamos National laboratory, employs a high-energy proton beam to image the properties and behavior of materials driven by high explosives. We will discuss features of the LANL pRad facility and the capability to perform velocimetry measurements in conjunction with dynamic experiments there.

4th Annual Photonic Doppler Velocimetry (PDV) Meeting
Nov 5-6, 2009 Austin, TX



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pRad Velocimetry

The LANL Proton Radiography facility (pRad) velocimetry team:

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Other members of the pRad team:

Joe Bainbridge, Bethany Brooks, Eduardo Campos, Deborah Clark, Camilo Espinoza, Jeremy Fait, Gary Grim, Gary Hogan, Nick King, Kris Kwiatkowski, Doug Lewis, Julian Lopez, Robert Lopez, Luke Lovro, Wendy McNeil, Fesseha Mariam, Mark Marr-Lyon, Alfred Meidinger, Frank Merrill, Deborah Morley, Christopher Morris, Matthew Murray, Paul Nedrow, Paul Rightley, Alexander Saunders, Cynthia Schwartz, Amy Tainter, Terry N. Thompson, Josh Tybo, Aleksandra Vidisheva

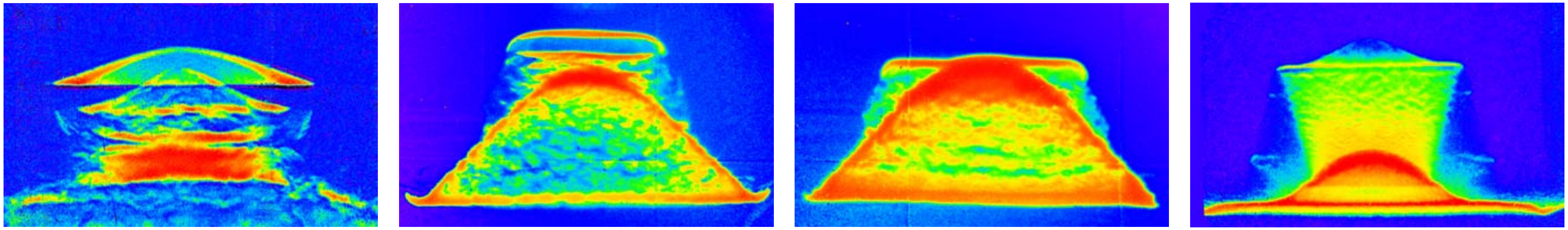
Other pRad collaborators (for velocimetry work at pRad and/or data shown in this presentation):

B Briggs, W Buttler, M Byers, D Dennis-Koller, D DeVore, S DiMarino, G Dimonte, E Ferm, M Furlanetto, M Furnish, C Gallegos, B Grieves, R Hall, J Hammerberg, A Harrison, R Hixson, D Holtkamp, D Huerta, J Huttenberg, A Iverson, J Lugo, S McDaniel, M Madlener, E Marsh, R Olson, D Oro, M Osborn, T Otteson, T Pierce, P Rigg, M Rightley, V Romero, A Rutkowski, D Shampine, B Simpson, L Tabaka, M Teel, G Terrones, W Tuzel, S Walker, R Williams, J Young, D Youngs, M Zellner

*** velocimetrists in red

Proton Radiography at Los Alamos National Lab:

Material and component characterization under dynamic conditions for stockpile stewardship without underground testing



Aluminum Copper Tantalum Tin

A series of proton radiographs of disks that have been explosively shocked from below. The radiographs reveal the internal structure of the materials in these extreme conditions. For example, the aluminum sample shows the formation of layers of spall while the tin sample displays characteristics of melting.

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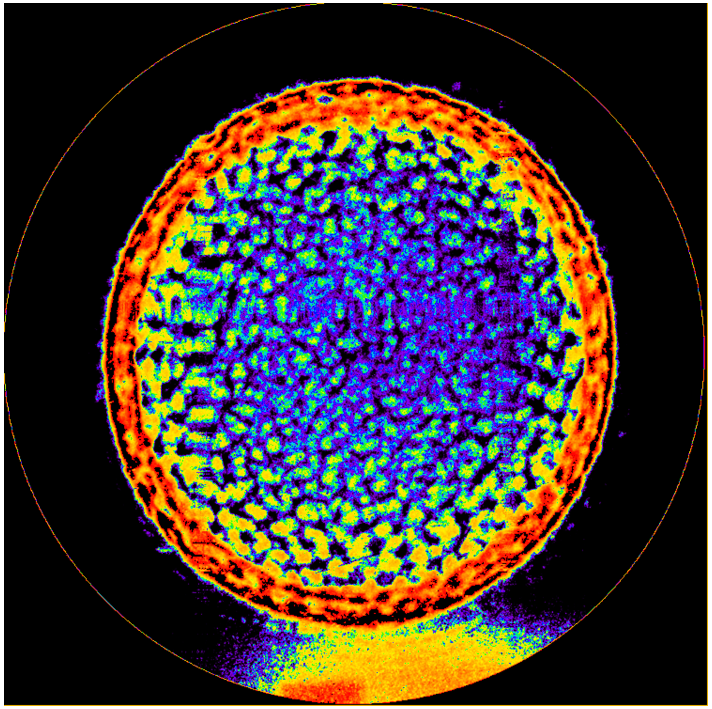
pRad Velocimetry

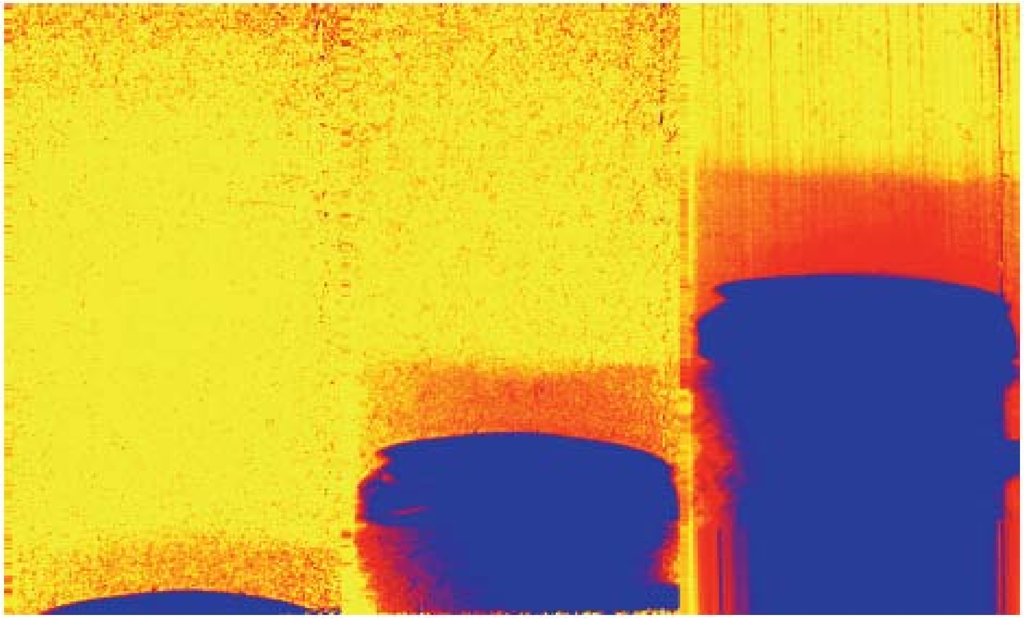
Why protons ?
(1) Penetrating power



The high energy of the beam gives it a penetrating power sufficient to see fine internal details in objects of a wide variety of densities, such as lead, plutonium, uranium, or high explosives -- shedding light on features under extreme conditions that are difficult to discern with x-ray imaging.

A hemisphere of high explosives is placed inside a hollow hemisphere of a uranium alloy and radiographed to study the failure mechanisms of U6Nb.

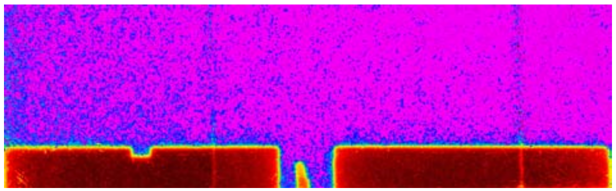
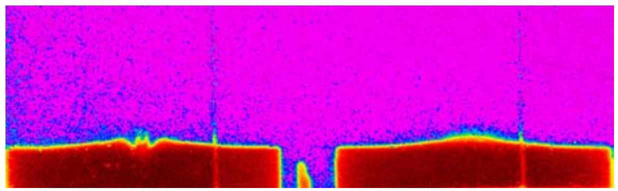
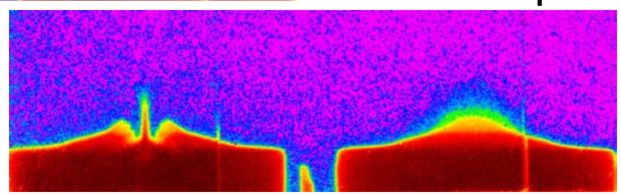
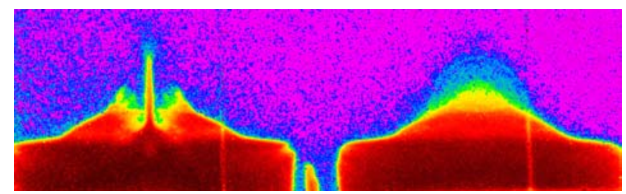
Why protons ?
(2) Charged particles can be transported and imaged



Since the proton beam is composed of charged particles, the beam may be focused with magnetic lenses to form images of the object far away from the interaction region for several great advantages, for example, it is possible to enhance the signal from selected materials.

These images depict an aluminum flyer plate traversing, from the bottom, a cylinder of xenon gas. The "bow wave" of denser shocked xenon gas can be seen as the reddened area preceding the flyer. Proton radiography is capable of imaging this tiny change in xenon thickness of 0.055g/cm2.

Why protons ?
(3) multiple images allow for radiographic movies

Using the proton beam from a particle accelerator allows for multiple images taken at a wide range of intervals, capturing a movie of the event where the frames may be spaced from one second to 10^{-7} seconds apart

This time-sequence series of proton radiographs taken at Los Alamos shows the evolution of a jet from a surface. Each image shows the front and side view of metal disks scored with a slot. The disks are explosively shocked from below and the damage resulting from the imperfect surface becomes evident over time.

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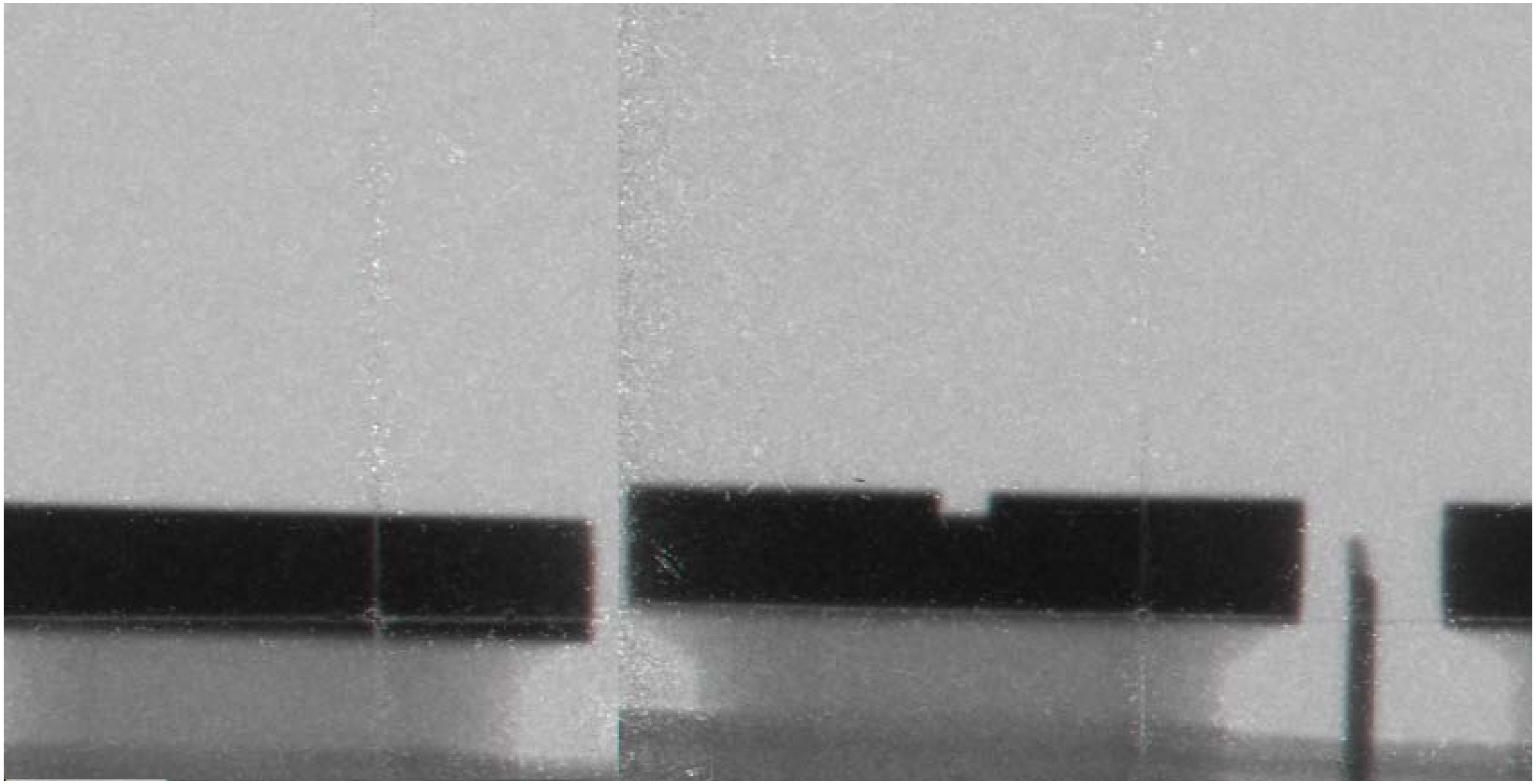
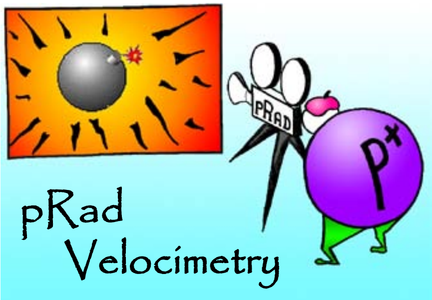
pRad Velocimetry

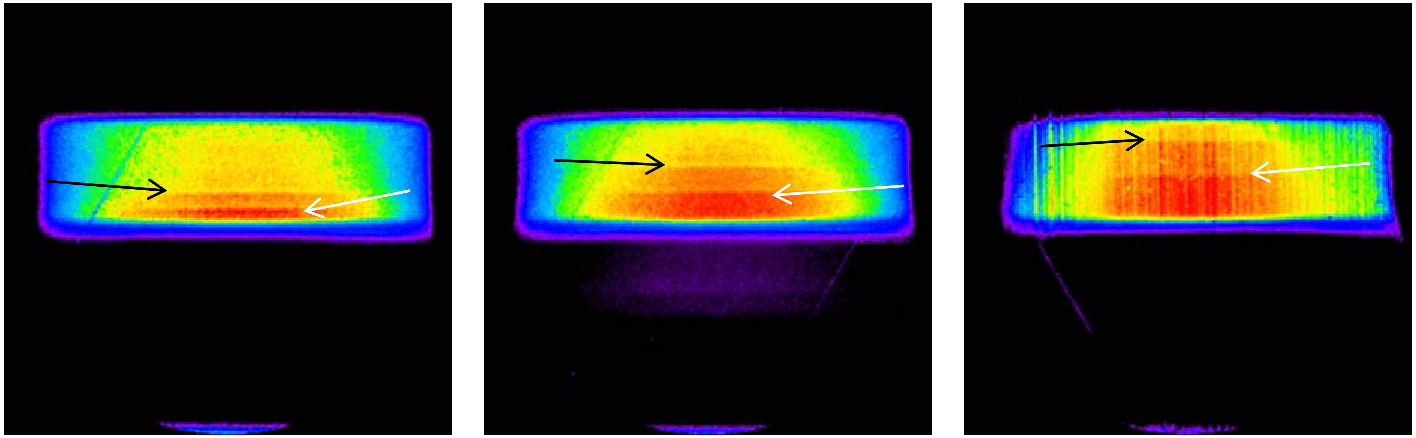
Why protons ?
(3) multiple images allow for radiographic movies



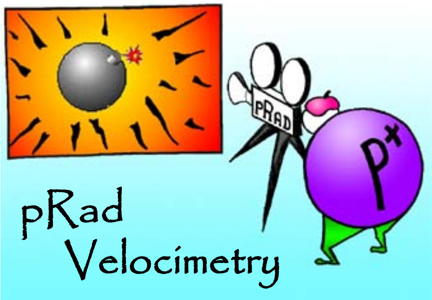


Why protons ?
(4) quantitative thickness measurements

Proton radiography makes possible quantitative measurements of material densities under extreme conditions, providing a diagnostic capable of predicting the performance of untested weapons components or aged components in the stockpile. This precision makes possible a range of fundamental science measurements as well.



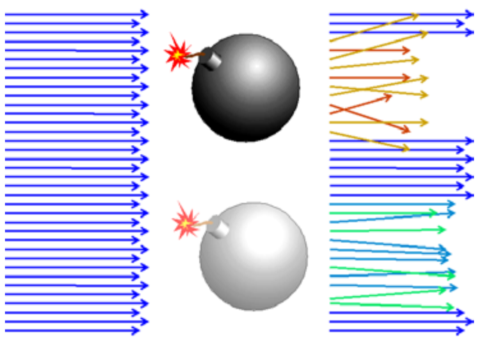
An iron disk hit from below by an aluminum flyer plate displays a shock front (denoted by the black arrows) and a region of denser iron (white arrows), where the extreme pressures have induced a phase change



How pRad works
(1) proton beam is provided by LANSCE

The efficacy and versatility of pRad stems from the ability to produce multiple proton pulses in an accelerator and use magnets to manipulate the proton beam. The beam for pRad is provided by the Los Alamos Neutron Science Center (LANSCE.) The proton beam is available in a wide range of timing sequences to meet the specific needs of each experiment. In this picture of the Los Alamos Proton Radiography facility, the proton beam enters from the left-hand side.

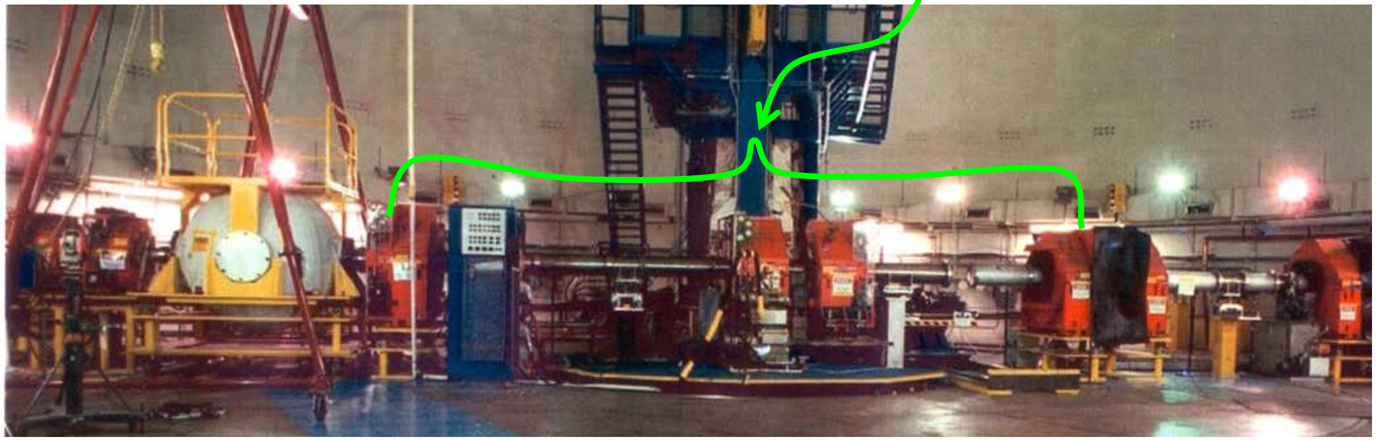
How pRad works
(2) protons interact with the test object



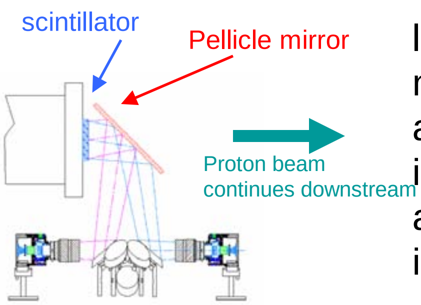
The interaction region is in a containment vessel specially designed to withstand the explosions that occur during experiments where protons pass through the test object. Here, protons are shown (in an exaggerated manner) to lose more energy and be deflected more if they traverse thicker or denser parts of the object than if they pass through thinner parts.

How pRad works
(3) protons are imaged to the camera locations

Strong magnets are used as lenses for the proton beam. (The magnets are the orange blocks – four magnets with drift regions make up one lens that images the interaction region.) This imaging process gives protons huge advantages over x-rays for imaging: The image location is far enough from the interaction region that background noise from scattered protons is minimized and explosives from the experiment do not damage the detectors. Different lens configurations can be used to magnify the view – 3x and 7x magnifiers have been built and used at LANSCE. Highly radioactive objects can be imaged without their radiation "fogging" the image.

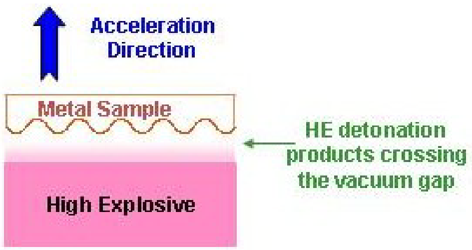


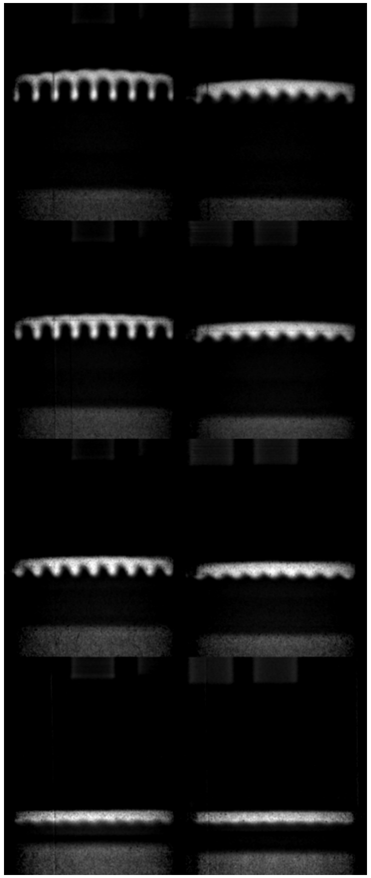
How pRad works
(4) cameras capture the proton images



The protons are imaged at camera stations in gaps in the beam line. Protons pass through a scintillator sheet which is viewed by multiple cameras. Each camera is gated on a different proton pulse and takes one frame of the movie. To the right of the camera station is seen another magnetic lens setup bringing the proton beam to another camera station so it can be imaged again. Currently, pRad is capable of taking 37 images in each experiment.

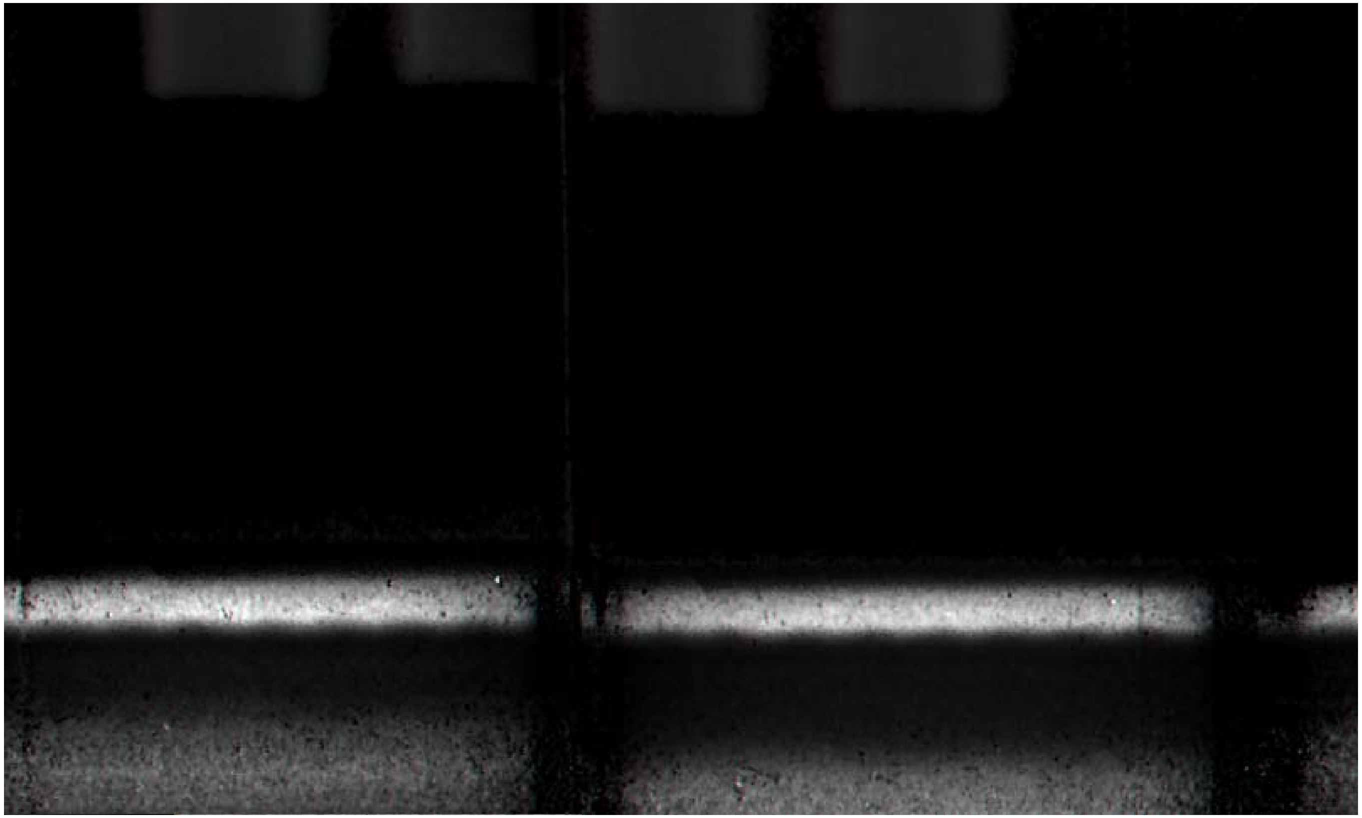
pRad experiments:
High-Strain-Rate Material Characterization



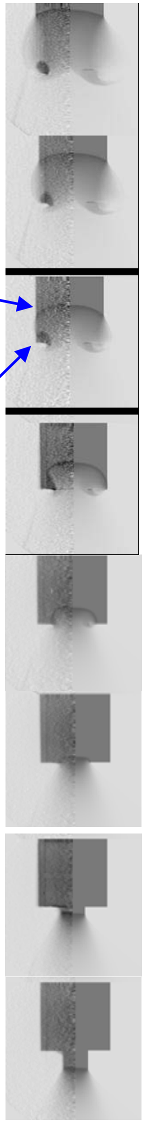


pRad is used to diagnose dynamic materials under extreme pressures, strains, and strain-rates. Here, the detonation products from high explosives (HE) rapidly accelerate a metal coupon without a shock. A sinusoidal (ripple) pattern has been machined on the coupon surface facing the HE, which encourages the onset of Raleigh-Taylor instability growth as the coupon accelerates. The strength of the metal coupon can be inferred from the growth rate of this instability. This technique has been used to understand the high-strain-rate strength of different metals manufactured under various processing techniques. From bottom to top, a series of proton radiographs shows the evolution of instability in two samples, one starting with an offset of 2mm from the HE, another offset 3mm.

pRad experiments:
High-Strain-Rate Material Characterization



pRad experiments:
HighExplosives Burn Corner Turning



Insensitive HE is used in nuclear weapons to make them safer. Proton radiography experiments help assure the reliability of weapons incorporating insensitive HE by fully characterizing the detonation properties. The picture on the right, from bottom to top, shows a time series of radiographs (left of the centerline) compared to a series of simulations (right of the centerline) for a detonation wave propagating through a cylinder of HE into a second HE cylinder of larger diameter. With insensitive HE, some undetonated HE remains when the detonation wave tries to turn the corner. The simulation did not predict this dead zone. This experiment provided valuable information for modeling efforts for stockpile stewardship.

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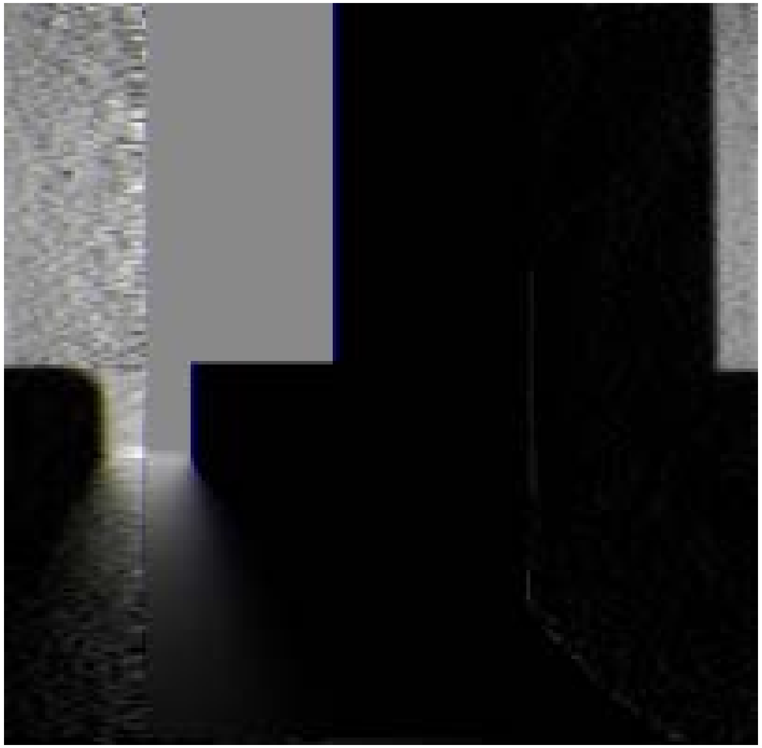
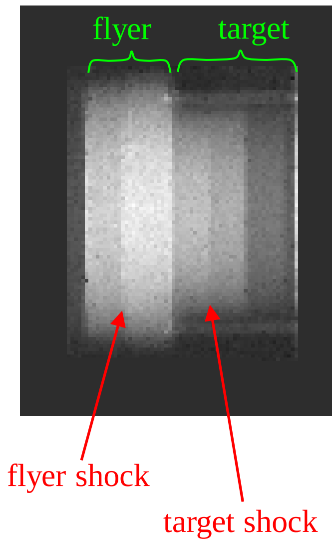
pRad Velocimetry

pRad experiments:
HighExplosives Burn Corner Turning



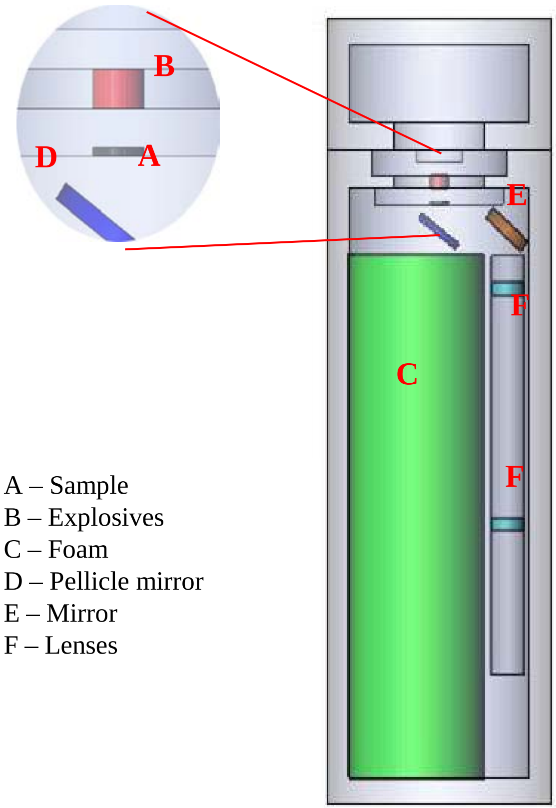
pRad experiments:
Material Characterization with a Powdergun



In addition to explosive experiments in containment vessels, the pRad team conducts experiments with a powdergun. This series of experiments with the pRad powdergun demonstrates the ability to observe the flyer impact and measure the particle and shock wave velocities in the materials. These experiments have provided direct density measurements of shocked metals with very high accuracy (<1%) and these data have been used to validate existing Equations of State for the materials studied. The radiograph at left shows an Al flyer plate (larger diameter) and an Al target shortly after impact.

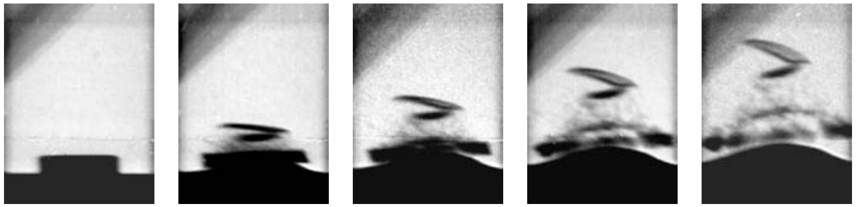
Another series of powdergun experiments displays the development of two shock waves in shock-compressed iron due to a shock-induced solid-solid phase transformation.

pRad experiments:
Contained “Thermos” experiments

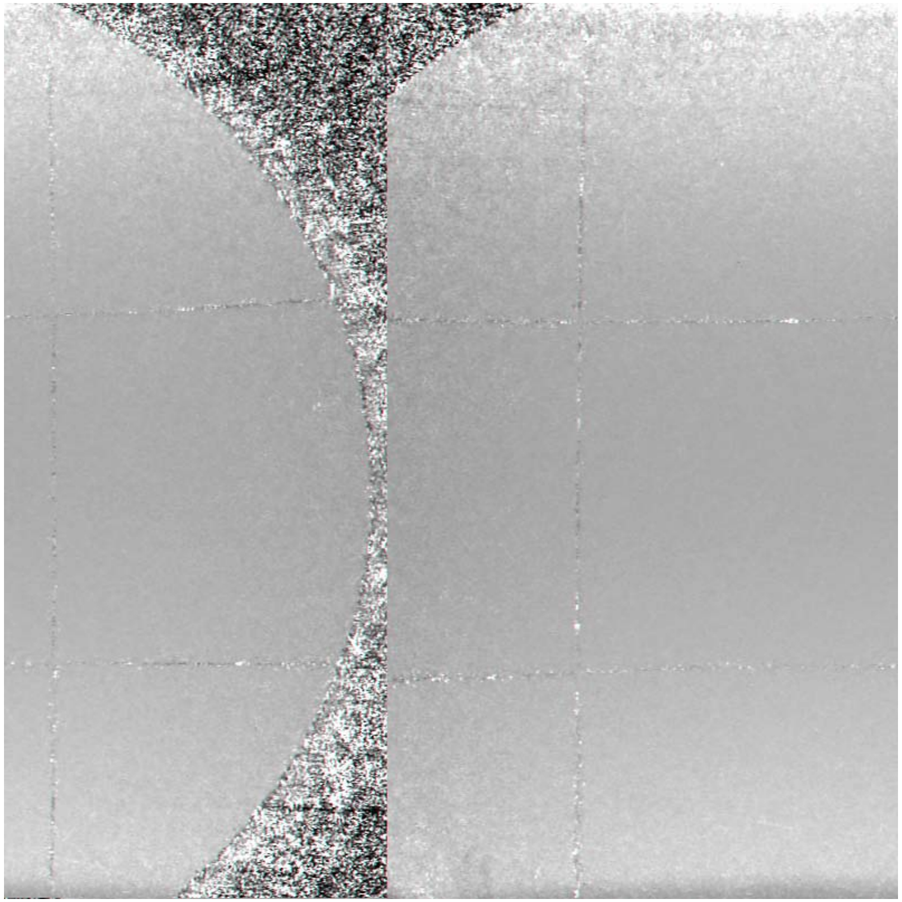


A – Sample
B – Explosives
C – Foam
D – Pellicle mirror
E – Mirror
F – Lenses

The penetrating power of protons makes possible detailed radiographic images of experiments conducted in sealed metal containment vessels. The sealed vessel provides the safety envelope to study samples of hazardous materials such as beryllium and plutonium. Pictured at left is a containment canister designed to catch the shocked sample in foam for later metallographic examination and also allow for optical velocimetry of the front surface of the sample. Below is a time series of radiographs of tin from this same configuration to compare its behavior to model predictions.



pRad experiments:
Contained "Thermos" experiments



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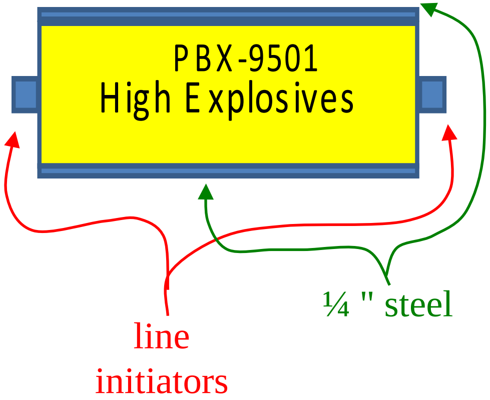
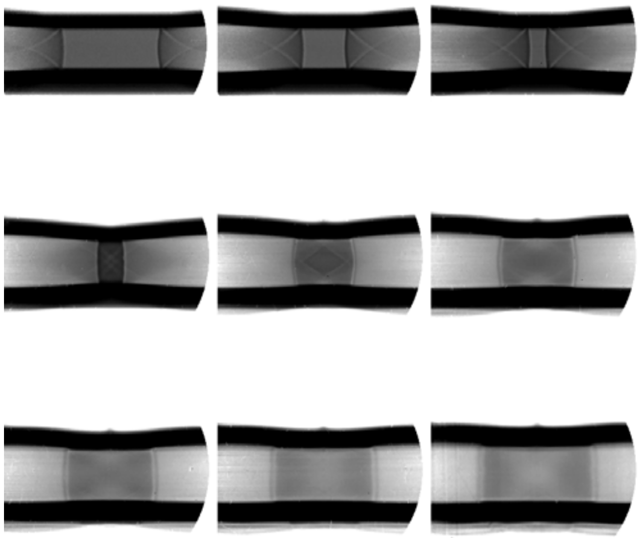
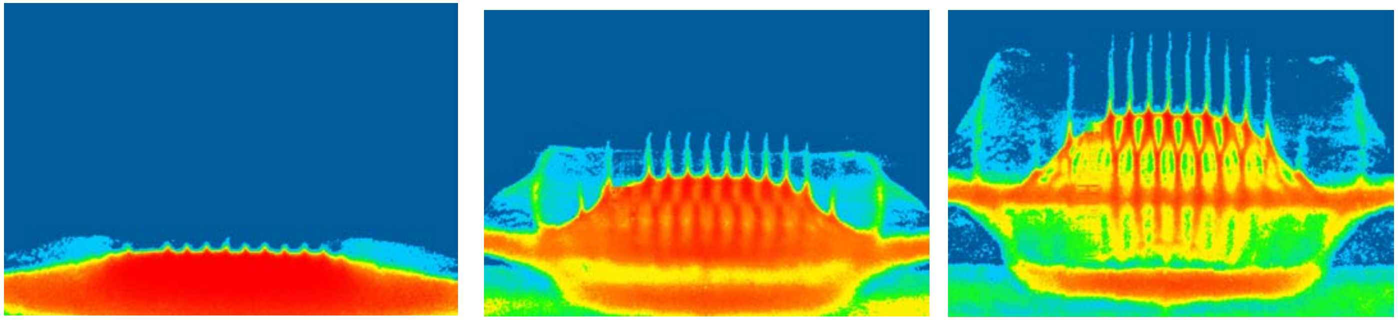
pRad experiments:
High Explosives Burn Colliding Wave





800 meV proton radiography has been used to diagnose HE burn characteristics and the equation of state of the resulting HE detonation products. Here, a piece of HE is line-initiated at each end. pRad images the detonation fronts as they approach each other in the explosives, and characterizes the shocks traversing the detonated HE products after pass each other.

pRad experiments: Richtmyer-Meshkov Instability



In these experiments, a disk of tin is prepared with sinusoidal perturbations on its top surface. This disk is hit from below by a fast flyer plate, causing a shock to propagate through the disk. The interaction of the shock with the perturbed top surface results in the signature spike-and-bubble of Richtmyer-Meshkov instability. These radiographs, from left to right, shows the evolution of this complicated structure, including the density variations below the surface. Data from experiments like these is used to test models vital for Stockpile Stewardship.

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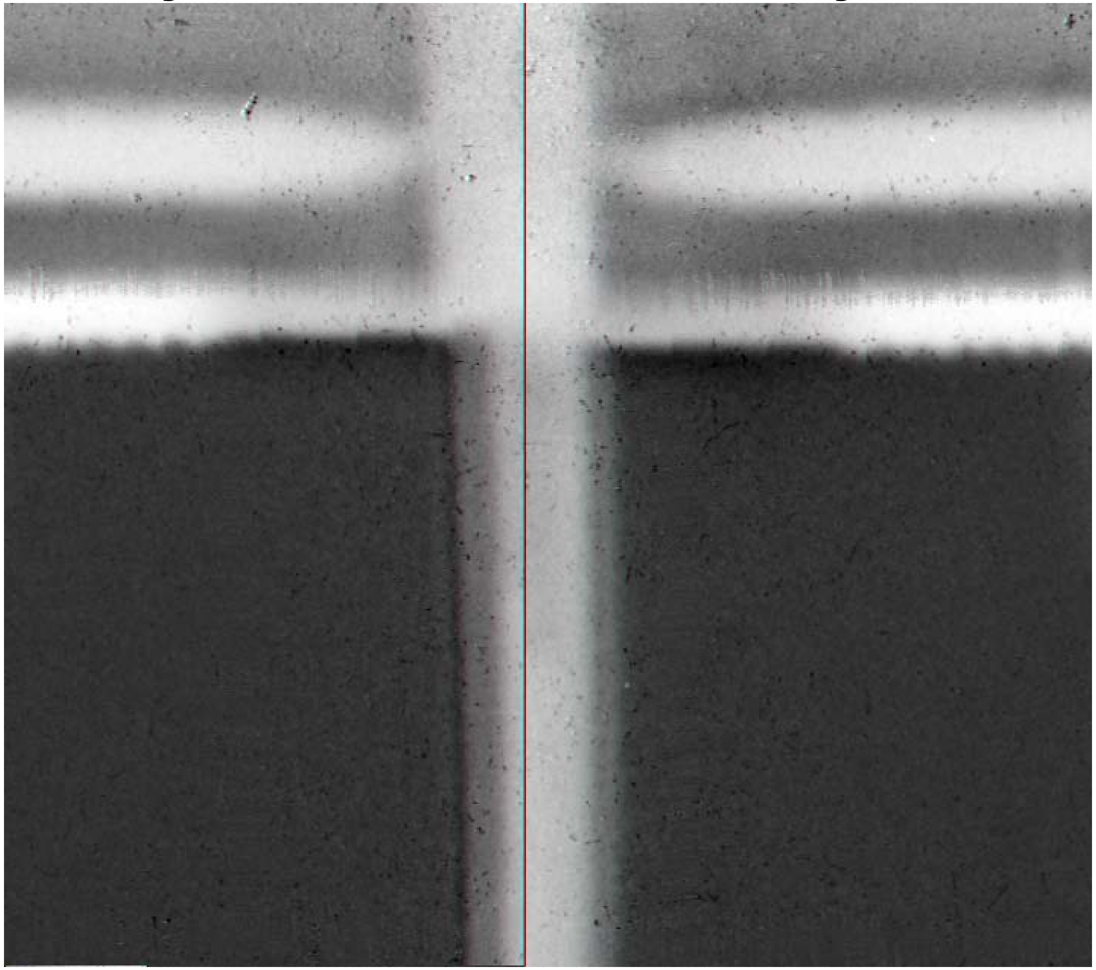
pRad Velocimetry

pRad experiments:
Richtmyer-Meshkov Instability



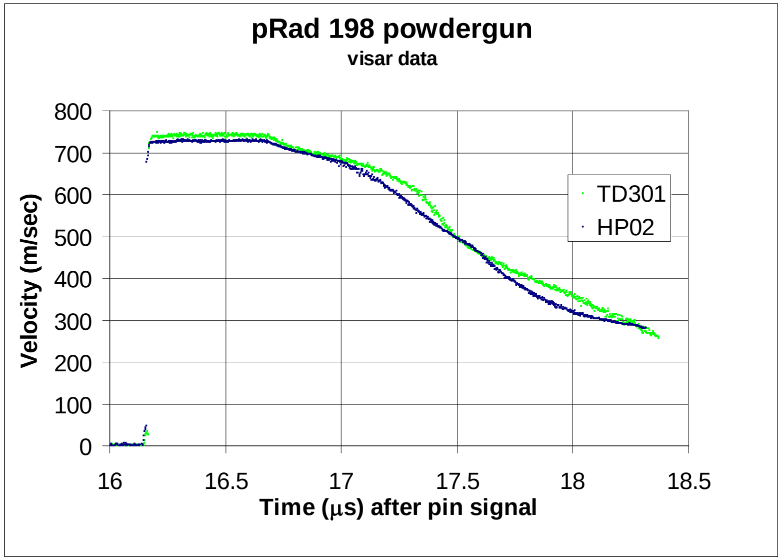
Velocimetry capabilities at pRad:

Visar

Up to 9 points of visar with single fringe constants

One single-point two-leg “mini-visar” (built by B. Marshall, NSTec Santa Barbara) ; upgradable to fast (450MHz) data recording

One seven-point single-leg homebuilt visar system



Above is a Visar velocity measurement of the surface of the Al Target piece from the powdergun experiment shown earlier.

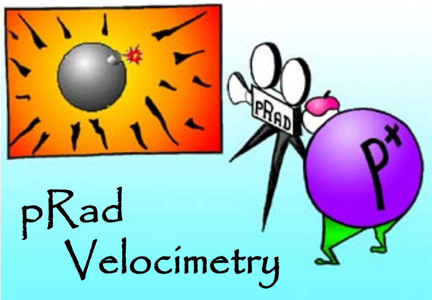
Velocimetry capabilities at pRad:

PDV

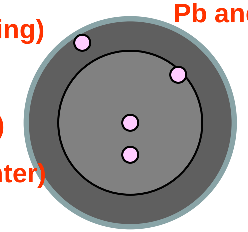
current capability of 6 PDV points, with an 8-point capacity using NSTec built 3U rack mount 13GHz modules

one 16GHz and three 8GHz Tektronix oscilloscopes, and two 5W 1550nm IPG lasers for experiments fielded at pRad

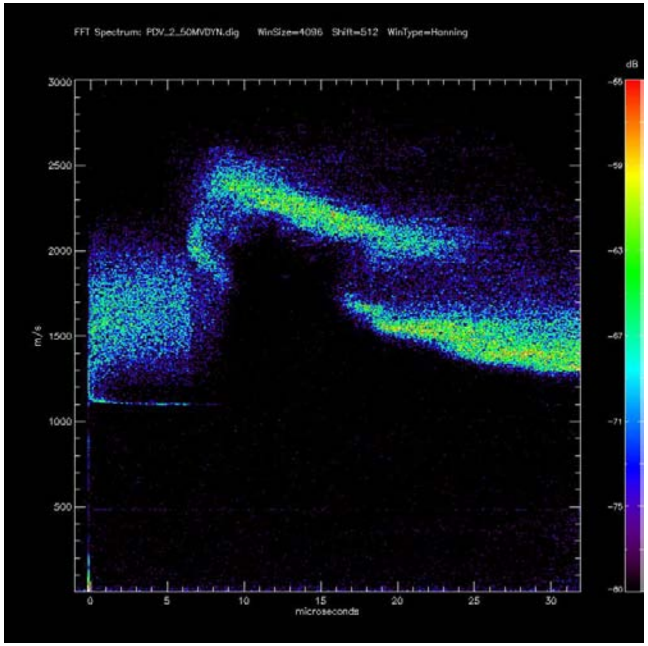
facility infrastructure could support fielding up to 48 points of PDV (if more equipment becomes available)



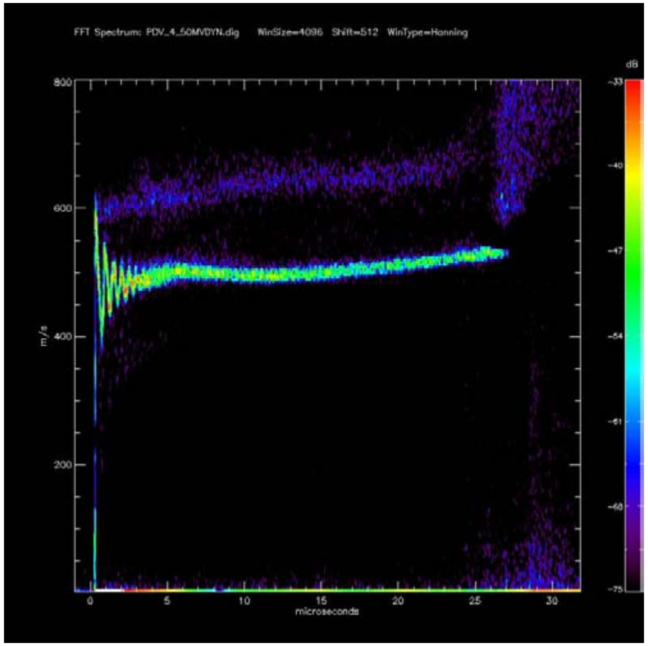
Velocimetry capabilities at pRad:



PDV - sample data from the Bacchus series



Probe 2



Probe 4

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pRad Velocimetry

Velocimetry capabilities at pRad:

The velocimetry team works with experimenters to meet their diagnostic needs, fully fielding PDV and/or visar in the pRad environment

Data can be taken in either classified or unclassified modes

Velocimetry is fielded on more than 80% of the dynamic experiments at pRad

Future work at pRad

Proton Radiography, and a similar technique with electron radiography are slated to play an integral role in LANL's future MaRie. MaRIE, a facility to study Matter and Radiation Interactions in Extreme Conditions, will utilize charged particle radiography to diagnose material properties in dynamic conditions.

Student/Postdoc Opportunities Available

Contact Dale Tupa, tupa@lanl.gov

pRad User Program

A user program provides experimenters the opportunity to work at the 800 MeV LANL Proton Radiography facility at the Los Alamos Neutron Science Center. The facility can handle both unclassified and classified experiments. There is a yearly call for proposals for experiments. A Program Advisory Committee evaluates the proposals; beam time is allocated based on the recommendations of the committee.

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